# EXHIBIT 1

UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

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| *In Re:* DRAM Antitrust Litigation | Master File No. M-02-1486PJH<br>MDL No. 1486 |
| This document relates to all direct actions. | |

***Expert Report of Roger G. Noll***

My name is Roger G. Noll, and I have previously submitted two reports on class certification in this matter.[1] I reside in Palo Alto, California, and I am a Professor of Economics at Stanford University.[2] My qualifications and experience are contained in my *Expert Report*. An updated version of my *curriculum vita* is included as Appendix A.

Since submitting my *Expert Report*, I have testified in *Seven Network v. News Limited* before the Federal Court in Sydney, Australia. I have also submitted expert reports in the following matters:[3]

*Joe Comes, et al., v. Microsoft*, District Court for Polk County, Des Moines, Iowa;

*Brian Bock, et al., v. Honeywell International,* Superior Court for the State of California, San Francsico, California;

*Vincent Fagan and Anthony Gianasca v. Honeywell International,* Superior Court for Middlesex County, Boston, Massachusetts; and

[1] *Expert Report of Roger G. Noll*, December 9, 2005 (hereafter "*Expert Report*") and *Reply Report of Roger G. Noll*, May 17, 2006 (hereafter "*Reply Report*").
[2] On September 1, 2006, I will retire from Stanford and become Professor Emeritus.
[3] The expert reports in the three Honeywell matters deal with the same issues and are almost identical.

*John McKinnon v. Honeywell International,* Superior Court for York County, Alfred, Maine.

I also have been deposed in the first and last of these matters.

**Assignment**

Attorneys for the plaintiffs have asked me to undertake an economic analysis of the alleged collusive behavior of the defendant manufactures of dynamic random access memory (DRAM). In particular, I have been asked to examine the evidence in this case to ascertain whether the information sharing by the defendants would be regarded by antitrust economists as collusive, to identify the most likely periods during which the defendants' engaged in this collusive behavior, and to assess whether this behavior was likely to have an effect on the prices of all forms of DRAM for all customers.

To carry out this assignment, I have read a large number of discovery documents and depositions, and the information submissions and plea agreements against four defendants (Elpida, Hynix, Infineon and Samsung) and several of their employees that arose from the investigation of the DRAM industry by the Department of Justice. In addition, I have read scholarly publications and trade press articles about the industry, and the material that was submitted with regard to class certification, including the order certifying the class. I have also examined the complaint against seven of the defendants that was filed by 34 states.[4] The documents which I have examined are either contained in footnotes to this or prior reports, or are listed in Appendix B. I have been assisted by the following staff members of the Brattle group: Nauman Ilias, Paul Liu, Armando Levy, and Catherine Taylor.

[4] *California, et al., v. Infineon Technologies AG, et al.*, U.S. District Court for Northern District of California, C-06-4333SC, July 14, 2006 (henceforth *State Complaint*).

Many of the issues that are relevant to the economic issues associated with the liability case have been covered extensively in my two prior reports. To avoid unnecessary duplication, I refer to the material in these reports only briefly and incorporate them as part of this report. In addition, my assignment does not include the quantification of the price effects of the collusive behavior of the defendants. Instead, this work is reported in the expert report of Paul Liu. My report focuses on providing an economic explanation of the conditions under which exchange of information about prices and output is likely to have an anticompetitive effect and whether these conditions were present in the DRAM industry during the period covered by the *Third Consolidated Amended Class Action Complaint* (henceforth *Complaint*) in this matter.

Because discovery is still in progress and because, owing to delays in obtaining transaction information from some of the defendants, data analysis is ongoing. I expect to continue to work on this matter over the coming weeks. I therefore reserve the right to supplement and revise my report as I find new information.

**Summary and Conclusions**

My analysis addresses the following issues. First, when did the defendants[5] engage in extensive exchange of information about prices and production? The purpose here is to attempt to determine the time periods in which the actions of the defendants may have caused prices of DRAM to be higher than would have been the case in the absence of the information exchange. Second, did each of the defendants participate in this information exchange? The purpose here is to determine whether any of the defendants were simply bystanders that profited from the collusive activity of others.

[5] Although this case involves many defendants that are divisions of the same multi-national corporation, I will refer to the defendants by the name of the parent company: Elpida, Hynix, Infineon, Micron, Mosel-Vitelic, Nanya, NEC, Samsung and Winbond.

Third, was the extensive exchange of price and/or production information among the defendants likely to have the effect of increasing prices? The purpose here is to determine whether conditions in the market are favorable to effective collusion. Fourth, was the effect of information exchange on prices likely to be confined only to "major customers" (the leading manufacturers of personal computers), or was it likely to affect all buyers? This analysis focuses on the linkage between the three major categories of sales: major contracts, other contracts, and spot transactions.

*Collusion Period*

The *Complaint* alleges that collusion among the defendants began on April 1, 1999, and ended in June, 2002. These dates correspond to the collusion period in the plea agreements between the U.S. Department of Justice and three of the defendants (Elpida, Hynix and Samsung), which ran from April 1, 1999 to June 15, 2002. The fourth plea agreement, with Infineon, dates the beginning of the collusion period as July 1, 1999.

My review of the evidence leads me to conclude that collusion among the defendants began earlier than this date, most likely in the spring of 1998.[6] While some defendants exchanged information about prices and/or production since at least the middle of 1997, the evidence that I have seen is not sufficient to conclude that these exchanges were frequent or involved a large proportion of sales among many defendants. Much of the contact among the defendants prior to 1998 was in the context of the SynchLink Consortium, a joint venture to design new DRAM technology to compete with Rambus DRAM. Discussions about SynchLink do not appear to be related to the matters at issue in this litigation. Consequently, I have concluded that the evidence for

[6] My conclusion is consistent with the *State Complaint*, which dates the beginning of the collusion in spring 1998 (paragraph 36, p. 11).

the period before the spring of 1998 is insufficient to prove the existence of an industry-wide, broadly targeted conspiracy.

The evidence shows that the extent and nature of communications among the defendants changed in 1998. Internal communications of defendant firms reveal more extensive contacts and information exchange beginning in April. These exchanges continued until shortly after the investigation of the industry commenced in May 2002. Thus, I conclude that June 2002 is appropriate for the ending date.

I also conclude that collusive activity among the defendants had a different character from during most of 2001. In late 2000, Hynix experienced a financial crisis that persisted through 2001. Beginning in early 2001, other DRAM suppliers, especially Samsung, sought to drive Hynix from the market by cutting prices, which resulterd in a price war. The evidence shows that the existence of a strategy to drive Hynix from the market was in place by late March 2001, in connection with negotiating contract prices for April. Coordinated action to set prices below cost in order to drive a firm from the market is a form of collusion, but an industry's customers are not harmed during the period while the concerted attempt to drive prices down takes place. Moreover, because the attempt to drive Hynix from the market failed, there was no period of recoupment in which competitors enjoyed greater unilateral market power and higher prices. Thus, I conclude that DRAM buyers did not suffer harm from the price war.

The attack against Hynix ended in November of 2001, and was replaced by another period in which the defendants sought to increase prices. Beginning in July of 2001, the defendants sought to coordinate a joint reduction in production. This effort initially was not effective, but it succeeded in December of 2001. Thus, the period of

predatory attack on Hynix was replaced by a second period of collusion to reduce supply and to raise prices that lasted until shortly after the Department of Justice commenced its investigation in May of 2002.

*Nature and Extent of Information Exchange*

The defendants engaged in three types of communication that were potentially anticompetitive. The first is general exchange of information and commitments about prices for contract and spot markets, without identifying the buyers at those prices. The second is exchange of information and price commitments about bids to a particular contract customer, including whether to participate in auctions that were set up by a buyer. The third is exchange of information about production plans, including coordination of reductions in output for the purpose of causing higher prices.

The evidence shows that all of the defendants, as well as several other DRAM manufacturers, engaged in some exchange of information during the collusion period. None of the defendants can claim to be an innocent bystander that simply profited from the collusive behavior of its competitors.

*Anticompetitive Effect and Harm to Purchasers*

Exchange of price information and bidding strategies among competitors is anticompetitive because it is likely to reduce the intensity of competition. In particular, the exchange of this information among sellers facilitates collusive behavior, whereby repeated exchange of information enables all sellers to settle upon common terms (price, delivery schedule, quality).

The likelihood that information exchange will have a persistent price effect is greater if conditions in the industry encourage coordinated behavior. Several factors

determine whether collusion is more or less likely to succeed. First, sellers that engage in collusive behavior collectively must account for a large enough share of the market that their coordinated behavior can affect the market price. Second, the industry must be sufficiently concentrated and must have sufficiently high barriers to entry that successful collusion requires the involvement of relatively few firms. Third, the products sold by each competitor must be regarded as close substitutes by buyers. Fourth, if sellers have no means for directly sharing the excess profits from a particular sale, the sellers must expect that their collusive behavior will cover a large enough number of separate transactions so that each will obtain a large enough share of sales at super-competitive prices to make continuing collusive behavior more profitable than using the information to undercut the prices of competitors in order to capture a much larger market share. Fifth, in some cases the institutional environment in which the industry operates, including government regulatory and trade policies, can facilitate collusion.

I have concluded that these factors all were present in the DRAM industry from 1998 through mid-2002, making information exchange among sellers likely to cause higher prices.

First, the cumulative market share of the defendants was high, exceeding 80 percent of sales in 2000 through 2002. In 1998 and 1999, Elpida and Hynix did not yet exist; however, if the Hyundai market share is used for Hynix and the NEC and Hitachi market shares are used for Elpida, the defendants' combined market shares were nearly 70 percent in 1998 and 80 percent in 1999. In the presence of barriers to entry, these market shares are far more than sufficient to give the defendants unilateral market power if they coordinate their prices.

Barriers to entry in DRAM manufacturing are high. Efficient fabrication plants are very large (and costly). In addition, DRAM, like all semiconductor technologies, undergoes rapid technological progress in chip design and production processes, so that successful firms must engage in considerable ongoing research and development to remain competitive. Thus, I conclude that the high market share and barriers to entry in DRAM are conducive to effective collusion.

Second, in the past decade, the DRAM industry has evolved from a highly competitive market structure to a reasonably concentrated one. In particular, between 1997 and 1999, a series of mergers, acquisitions and exits caused the Hirschman-Herfindahl Index (HHI) in sales by DRAM merchant suppliers to rise from under 1000 (which is generally regarded as reasonably competitive) to over 1400 (which is in the "grey zone" where the extent of competition depends on other structural features of the market). By 1999, five firms (Hyundai, Infineon, Micron, NEC and Samsung) accounted for 75 percent of sales, which, in the presence of entry barriers, is more than sufficient to cause collusion just among these five to have a substantial anticompetitive effect.

Third, the DRAM industry produces standardized products. DRAM products are built to industry-wide technical standards for use in a wide variety of products that are manufactured by numerous different firms. Common technical standards are a means to facilitate interoperability among components of electronic devices such as computers, personal communications devices, game boxes and digital media players, among others. Because technological progress is rapid, new DRAM products are offered roughly every two years.[7] During each transition, a DRAM firm must design products in the new

[7] Technological progress involves both increasing the size of DRAM within a technology and changing technologies. As explained in my *Expert Report*, during the period at issue in this litigation, the industry

technology and qualify them for use in computers and other electronic equipment. The defendants, as leading DRAM manufacturers, develop and qualify these products at roughly the same time, and once products in a new line are qualified and in production, the products of different manufactures are virtually perfect substitutes. Consequently, for purposes of economic analysis, DRAM products within a technological family are homogeneous commodities. Thus, the similarity and substitutability of DRAM products is favorable to effective collusion among sellers.

Fourth, the market for DRAM includes a large number of buyers, many of which are more or less constantly negotiating prices and making purchases. No buyer accounts for a sufficient proportion of sales to be able to exercise unilateral market power, and the demand side of the DRAM market is far from being sufficiently concentrated to expect buyers collectively to exercise any monopsony (buyer) power. In addition, the largest buyers typically sign contracts with several vendors that call for frequent renegotiation of prices and that allow the buyer to vary the proportion of its purchases among vendors. Consequently, at a given time many transactions are being negotiated, so that each firm has many opportunities for sales so that it could share in the excess profits derived from collusive pricing. Moreover, frequent sales enable each member of a collusive group of sellers to be able to detect very quickly if its competitors are systematically undercutting promises to competitors about prices. Thus, the market institutions in the DRAM industry are favorable to effective collusion.

Fifth, the DRAM industry has had a sequence of antidumping actions, largely initiated by Micron, the largest U. S. DRAM manufacturer. Antidumping disputes are

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made the transition from 64Mb to 128Mb to 256Mb DRAM chips and from EDO DRAM to SDRAM, and entered the transition from SDRAM to RDRAM and DDRDRAM.

regarded by economists as facilitating collusive pricing. In 1993, the U. S. imposed a countervailing duty on South Korean DRAM manufacturers. Three years later, the case for the countervailing duty was reviewed, and in July 1997 the duty was extended.

Antidumping cases encourage both importers and domestic producers to raise prices – the former to avoid further antidumping claims and the latter to establish a high base price against which to evaluate their future antidumping claims against importers. Thus, I conclude that antidumping rulings created an environment that encouraged collusion among DRAM manufacturers.

*Breadth of Impact*

Thus far, the plea agreements between the Department of Justice and four of the defendants have focused "on certain original equipment manufacturers of personal computers and servers ('OEMs')"[8] that were identified as Dell, Hewlett-Packard, Compaq, IBM, Apple and Gateway.[9] These cases leave open whether the collusion extended to other customers.

In my previous reports, I discussed this issue at length, and I incorporate this analysis and evidence of that issue into this report. As a matter of economic analysis, collusion against only some firms in an environment in which all customers compete in downstream product markets would be ineffective. Higher input prices to only some producers would cause the latter to have higher prices, and hence to enjoy fewer sales, relative to competitors that were not the target of collusion. In addition, the evidence shows that contract negotiations with OEMs center around recent developments in spot market prices. My *Reply Report* cites extensive internal documents and other evidence to

[8] *U.S. v. Hynix*, U.S.D.C Northern District of California, *Information*, April 21, 2005, p. 2.
[9] *U.S. v. Hynix, Plea Agreement,* May 11, 2005, p. 3.

show that industry participants believe that spot prices and contract prices move together. Moreover, my *Expert Report* shows that average prices for major contract customers, secondary contract customers, and spot customers exhibit the same pattern of movements over time.

Here I extend that analysis by constructing an econometric model of the relationships among these prices. The results of this analysis confirm the conclusions of the prior reports: all of these prices are extremely highly correlated, and there is a clear causal relationship running from spot prices to contract prices for both major and secondary buyers. These results are not consistent with the claim that collusion among the defendants affected only contract prices with the largest OEMs.

The remainder of this report explains the basis for these conclusions.

**The Period of Collusion**

The *Complaint* in this case alleges that the defendants engaged in collusion over prices and output plans beginning in April 1999. This allegation is consistent with some but not all of the charges brought by the Antitrust Division and the resulting plea agreements involving four of the defendants and several of their employees. Specifically, the charges and guilty pleas about price fixing by Hynix, Elpida and Samsung state that the collusion period was April 1, 1999, through June 15, 2002, whereas the charge and plea agreement involving Infineon dates the collusion period as July 1, 1999, to June 15, 2002. The discrepancy in the dates raises the issue of when the collusive exchange of information and the resulting anticompetitive effects actually began. Samsung was the largest supplier of DRAM chips in the late 1990s with a market share exceeding 20 percent, so that collusion among the other defendants who have pleaded guilty to price

fixing would have been substantially more effective if Samsung participated in the collusive behavior. Dating the beginning of the collusion also is important to implement the "before-after" test for the effect of collusion on pricing, as described in my *Expert Report*. For these reasons, I have conducted my own examination of the evidence in this case to determine independently when the collusive activity began as well as when it was likely to effect prices.

Discovery in this case has produced an enormous amount of evidence that employees of the defendants engaged in extensive exchange of information about prices and production plans throughout the period alleged in the *Complaint*. Working under my direction, staff economists at the Brattle Group have read all of the internal documents and depositions in this case to find instances in which employees of one of the defendants engaged in the exchange of information about prices or production with any other manufacturer of DRAM, either generally or in the context of a particular DRAM buyer. I then read the documents that they had identified. Most of this evidence pertains to the years 2001 and 2002. Nevertheless, the evidence shows that information sharing took place in 1997, and was extensive from 1998 to 2000.

Two Hynix (at that time Hyundai) employees date information exchange to no later than the fall of 1997. Charles Byrd (Hynix) testified that he began exchanging information with Devin Cole (Samsung) after becoming strategic account manager in 1996 and with Dan Morrissey (Micron) one year after becoming strategic account manager.[10] Paul Palonsky (Hynix) testified that in the fall of 1997 he began to exchange price information with competitors, including NEC, Samsung and Toshiba.[11] Although

[10] *Deposition of Charles Byrd.*
[11] *Deposition of Paul Palonsky.*

Mr. Palonsky mentions several names of employees of competitors with whom he exchanged information, he does not date the beginning of exchanges with specific people.

Other evidence confirms Mr. Palonsky's and Mr. Byrd's recollections. Discovery has produced internal communications at Hynix dated between September and December 1997 involving both Mr. Byrd and Mr. Palonsky that report information exchanges about prices to Dell and IBM with Hitachi, Infineon, Micron, NEC, Samsung and Toshiba.[12]

I have cross-checked these reports of information exchange to the extent that it is possible to do so, given that many relevant employees have not been deposed and that among those who have, several either refused to testify or stated that they could not recall any details about information exchange. Other evidence has minor conflicts with the recollections of the Hynix employees. For example, Mr. Morrissey testified that his information exchanges with Hynix employees began in 1998, not 1997 as reported by Mr. Byrd. I have found no internal communications or deposition testimony from any firm other than Hynix that reports exchange of information about prices and output in 1997, even though the Hynix evidence documents that information exchange did occur.

The situation is very different for 1998. Micron has provided a summary of the extent to which its employees had contact with employees of other DRAM suppliers.[13] Micron reports that the following Micron employees engaged in sharing information with competitors during 1998: Mike Grant, Bill Lauer, Dan Morrissey, Mike Sadler, Steve Thorson, Keith Weinstock, Gary Welch, and perhaps Joe D'Esopo. The competitors involved in these exchanges were: Hynix, Infineon, NEC, Samsung and Toshiba, which, along with Micron, were the six leading sellers of DRAM in 1998.

[12] HSA20009924, HSA20023553-7, HSA20023735-6, HSA20023991-2, and HSA20023996-4000.
[13] *Draft Statement of Conduct*, Micron.

Internal company documents confirm that extensive and frequent information exchange took place no later than April 1998. Among these are the following.

- April 20, 1998: exchange of information about the "average OEM price" between Hynix and Toshiba.[14]
- April 23, 1998: report of conversations between Hynix and competitors about prices to IBM, with reports of prices quoted by Oki and Samsung.[15]
- April 24, 1998: report of conversation between Micron and Samsung about placing a floor on "64 meg" DRAM price.[16]
- May 28, 1998: Report of conversation between Hynix and Samsung about prices of 16Mb and 64Mb DRAM for Compaq.[17]
- June 24, 1998: Report by Hynix employee of hearing about a "meeting arrangement" among Micron, Mitsubishi and Samsung.[18]
- June 29, 1998: Reports of conversations between Micron and Hynix about production cutbacks and about pricing to Acer and IBM.[19]
- July 29, 1998: Report of exchange of information about prices for Dell between Infineon and Samsung.[20]
- August 17, 1998: Reports to and from Paul Palonsky of exchange of price information regarding IBM between Hynix and Samsung and of IBM pricing by Fujitsu, Hitachi, Mitsubishi and Toshiba.[21]

[14] HSA3003890-1.
[15] HSA3011548-9.
[16] MU00475748.
[17] HSA3004620.
[18] HSA3030039.
[19] MU00205955.
[20] ITNA00025552.
[21] HSA3011963-4.

- August 20, 1998: Hynix communication reporting IBM prices of Fujitsu, Hitachi, LG, Micron, Mitsubishi, NEC, Samsung and Toshiba.[22]
- August 20, 1998: Hynix document about IBM prices reporting (English translation): "Most suppliers … consent to the fundamental idea that price might have to be increased because the price difference is too big from the spot price and assert that they will increase [the price] when exchanging information among competitors. However, nobody doesn't seem to want to initiate the price increase since they don't want to be criticized by their customers about their first move… Although Our Company's price for August was not within the competitive range, it is [our] recommendation that we adjust on a small scale considering the request we had for continuous proceedings of certification and the information of the competitors (problems with supplying)… However, it is our strong recommendation that we maintain the price of other products at August level. Of course, what is important is the status of the competitors. Please figure out the competitors trends in sites including Europe."[23]
- August 20, 1998: Hynix document about IBM pricing that states (English translation): "Whether to readjust the price during final pricing is supposed to be determined in accordance with the competitors' movement and Our Company's relationship strategy with IBM… I will collect and input the price information of the competitors by the end of this week."[24]
- August 24, 1998: Reports by Hynix employees of conversations with NEC,

[22] HSA3051324-8.
[23] HSA0449931.
[24] HSA0449932.

"Company H," and "Company S" about IBM pricing.[25]

- August 26, 1998: Report of conversation between Hynix and Samsung about Apple pricing, also stating plans to obtain Micron price.[26]
- August 26, 1998: Report by Charles Byrd (Hynix) of conversations with Samsung and TI about price to Dell.[27]
- August 29, 1998: Report of conversation about pricing to Apple between Hynix and Samsung.[28]
- September 1, 1998: Hynix report to Charles Byrd stating: "From what I hear, Mits is going to raise the price somehow ($68 for 8Mx64) and obviously SS is going to raise and other vendors are trying to join them. I think its time for us to do something."[29]
- September 3, 1998: Internal message to Charles Byrd (Hynix) regarding Dell and Gateway prices that states: "I understand that it is tough raising price at Dell and Gateway since Japanese guys are still waiting and seeing market situation… I'll survey Japanese movement closely with other ww sales manage and mktg guys and will cross-check with you. Please try to persuade other Japanese Sales manager to participate in our movement if possible."[30]
- September 17, 1998: Hynix document reporting IBM price proposals communicated from LG and Samsung.[31]
- September 18, 1998: In response to previous e-mail, Paul Palonsky (Hynix) is

[25] HSA0449934.
[26] HSA3035349.
[27] HSA3028030.
[28] HSA3044765.
[29] HSA3044806.
[30] HSA3044805.
[31] HSA3036551.

asked: "Please bring all the available competitive information information on the first pass pricing - Japanese, Micron, Siemens, Korean - with you when you are coming to Korea."[32]

- September 25, 1998: Report from Charles Byrd (Hynix) stating: "For Dell October pricing I have gathered the latest information from the competition" with information about Infineon (Siemens), Micron, Mitsubishi, NEC and Toshiba.[33]
- November 9, 1998: Hynix internal communication stating: "We have been sharing this market situation with LG and Samsung locally and addressed our idea of increasing the prices at the major OEMs, say, effective November 16. We didn't agree on the range of increase. Samsung welcomed. LG mentioned that their prices are already in the highest level at each account and so asked us to come up."[34]
- November 10, 1998: Internal communication from Charles Byrd (Hynix) reporting that "Samsung pulled a sneaky" by not raising its price to Dell, and quoting the current prices of Hitachi, Infineon (Siemens), LG, Micron, Mitsubishi, NEC and Toshiba.[35]
- November 11, 1998: Reply to above reporting that Samsung confirmed the price deviation and stating: "For December pricing, my counterpart at Samsung promised to keep higher than $80."[36]

The conclusions to be drawn from the evidence are as follows. First, by no later

[32] HSA3015280.
[33] HSA3017813-4.
[34] HSA3068410.
[35] HSA3063762-5.
[36] HSA3063766.

than April 1998, communication was extensive among all of the major DRAM suppliers about prices generally and with respect to major OEMs. The only defendants (or defendant predecessors in the case of Elpida, Hynix and Infineon) who do not appear in these 1998 price reports are Mosel-Vitelic, Nanya and Winbond. Moreover, firms that are not defendants – Hitachi, LG, Mitsubishi, Oki, Toshiba – also were engaged in information exchange. Second, by late August, when prices were being set for September, the major suppliers were explicit in making commitments to each other about future price changes. On the basis of this information, I conclude that extensive communication among the firms named above began approximately a year earlier than the beginning date of collusion in the *Complaint* and the plea agreements with the Antitrust Division, and attempts to engage in explicit price fixing began at least eight months earlier. Hence, the search for potential anticompetitive harm arising from collusion should begin with the middle of 1998.

Exchange of information and attempts to coordinate pricing continued in 1999. For example, on May 24, 1999, a Hynix document reports: "We have no idea that Micron has changed the price again but as far as we figured out through talking with them this morning the lowest price they have as of this morning is $46.50."[37] An earlier e-mail in the same string states that "we would better not the price leader, just follower. Meantime, however, we would get together with Samsung and ask them to suggest Micron to have a joint management meeting for price control in the future."[38] A later message, responding to the above chain, states: "One of the advantage of being a big three is to have the controlling power over the price and we need to exercise this… One

[37] HSA3097665.
[38] HSA3097666.

of our concern is that it is against the antitrust law to set up a certain cartel price… Andy suggested to encourage Samsung as the initiator. Why not, if they accept? We need to have a communication channel open among the big three or four. Each management should share their concern about pricing while not violating the law."[39] Of course, the communication channel was not limited to three or four firms. On August 10, 1999, an Infineon document states: "Yesterday we had a very successful meeting with the marketing people of Hyundai. They had presented a lot of very useful data which they have collected on a quarterly basis from the competition. They meet quarterly with Samsung, the top five Japanese and top five Taiwanese vendors."[40] A Mosel-Vitelic document dated August 23, 1999, reports a meeting with Winbond to exchange information about prices.

Discussions about coordinating reductions in production also occurred around the time that the government plea bargains set as the beginning of collusion in 1999. On April 28, 1999, Infineon Vice President Jan du Preez wrote of a conversation with Micron Vice President Dan Baldwin in which he stated that "we are interested to talk about getting volumes from them according to his offer. He backtracked a little and said Micron wants to avoid Infineon increasing capacity and if such a concept could achieve this we should talk. I asked him to make a suggestion and he promised he will put it on paper after talking to Steve Appleton today… Last night Julian Hawkins (Samsung) phoned me and had a lot of questions about Infineon strategy and future plans. He said Samsung 'management' is concerned about the rapid growth of Infineon."[41] Documents reporting exchange of information continue through 1999 and 2000.

[39] HSA3097692.
[40] ITNA01058999.
[41] ITAG00187448.

The evidence shows that the nature of the communications among the defendants changed in early 2001. As background, in late 2000 Hynix began to suffer enormous losses, causing its operating profit to shrink from plus $513 million in 1999 to minus $1.2 billion in 2000.[42] While the exchange of price information continued in the first half of 2001, the character of the reports about pricing changes.

In the first half of 2001, some documents continue to report the same pattern of information exchange to coordinate pricing, but with comments indicating a failure to arrest the fall in prices. A Samsung document from March reports that Hynix sought to increase prices, but "the local Hynix account manager believes that any attempt to increase at Compaq 'will not stick', and the first supplier to push the crease will lose significant business in April."[43] Another Samsung document states that all major competitors agree that a price reduction is warranted, and that Samsung intends to make the price move early to gain an advantage.[44] A Hynix report states: "I had dinner with Samsung marketing guy yesterday. The guy clearly said that Samsung would kill Infineon with 256M DRAM. This means that Samsung will play 256M DRAM without price guideline."[45] Another Hynix document states that Infineon would be willing to be part of an attempt to shore up prices, but did not know how to implement it.[46]

Several messages are explicit that one purpose of the price cuts was to kill Hynix. A Micron internal communication of March 2001 states: "I also think now is the time to do everything in our power to make it very difficult for Hynix to get that so badly needed cash. This potentially weakens their position in the eyes of potential Hynix investors or

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[42] Hynix 2000 Financial Report, pp. 9-10, at www.hynix.com/eng/04_lr/down/audit/00audit_eng.pdf.
[43] SSI0010044894-6.
[44] SSI0005009247-8.
[45] HSA: Kassack 108200.
[46] HSA: Byrd 010337.

bank bailout efforts."[47] An Infineon document from June 2001 reports a communication with Samsung: "I talked with our friend Mackowiak… They want to kill Hynix and take their market share. They are ready to fight to drive prices down – intentionally… The next months might be horrible."[48] Another Infineon report, this from October 2001, states: "I talked to Dieter Mackowiak from Samsung… Samsung will proceed to take market share and making life difficult for all 'weaker' competitors."[49] An exchange of e-mails between Rudd Corwin (Infineon) and Dieter Mackowiak (Samsung) in October reads as follows: Corwin – "Can't you guys finish this off?" and Mackowiak – "Unfortunately we can not stop this but we are trying to show investors that there is no chance for Hynix to survive and them to return their money. That's all I can say in an e-mail!!!!!"[50] Hynix apparently was aware that they were the target. One internal communication from Charles Byrd in May 2001 states: "I am going to have a dinner meeting with Mr. Florian, VP, Sales and Marketing, Infineon next Monday. I will find out if Infineon really wants us out of the market."[51] This and other evidence does not pinpoint when communications designed to increase prices failed, but the documents indicate that this change had taken place by late March, 2001.

Attempts to re-establish collusive prices by firms other than Hynix apparently began in earnest about mid-year. On June 27, a Micron report states: "We have heard rumors from one of the Taiwan DRAM makers that there is a meeting scheduled with all the Taiwan DRAM makers over the next week to discuss raising their pricing. We know that Samsung/Hynix and Infineon have had similar discussions (of course price

[47] MU00128258-9.
[48] ITNA01137730.
[49] ITNA01148349.
[50] ITNA01068508.
[51] HSA: Byrd 109550.

discussions are not legal in the US so we have not participated in any of the discussions)."[52] The first mention of the most elaborate effort to end the price war is a July 3, 2001, Hynix internal message that states: "Gary Swanson told me yesterday that Mike Sadler wanted to discuss with us on the measures to stabilize the market price. Good move, right? Farhad got the same message from Mike this morning."[53]

During the summer and fall of 2001, the evidence shows that Micron Vice President Mike Sadler, who had various titles but was the person in charge of DRAM pricing, assisted by Infineon and Hynix, put forth a major effort to end the price war.[54] Micron's *Draft Statement of Conduct* reports that Mr. Sadler talked with two CEOs of competitors in 2001, Y. W. Lee of Samsung and Ulrich Schumacher of Infineon, and met regularly with Vice Presidents (with various titles) of competitors to discuss prices and industry conditions as follows: Tom Quinn of Samsung (sometimes several times per week 1998-2000, less frequently fall 2001-June 2002); Peter Schafer of Infineon (once or twice a week from May 2001 until June 2002); Gary Swanson of Hynix (once or twice a month from late 1999 or earl 2000 until June 2002); Ken Hurley of Nanya (five to ten times between December 2001 and June 2002); Farhad Tabrizi of Hynix ("handful" of contacts until May 2002 – no beginning date); Charles Kau of Nanya (four to eight conversations in the summer and early fall of 2001); and John Seto of Mosel-Vitelic (talked "from time to time" but no dates given).

Mr. Sadler's conversations with high level executives of Micron's competitors included discussion of prices or excess supply in the industry, and sometimes both. In each case for which contact dates are provided at least some of the contacts took place

[52] MU00128826.
[53] HSA: Swanson 059125.
[54] *Draft Statement of Conduct*, Micron, p. 18.

during the crucial period between the summer of 2001 and June of 2002 when the defendants attempted to end the price war, establish agreements about joint reductions in supply, and re-establish the old system of coordinated pricing. Micron CEO Steve Appleton confirmed in his deposition that in October 2001 Mr. Sadler visited someone at Hynix, perhaps Schafer and Schumacher at Infineon, Seto at Mosel-Vitelic, Kau at Nanya, and Lee at Samsung.[55] These contacts correspond to a highly secretive trip involving Micron and Infineon personnel.[56]

Mr. Sadler sought to coordinate mutual reductions in production among the defendants. The last to agree was Samsung, after Hynix succeeded in obtaining a $7 billion bail-out.[57] As Mr. Schaeffer of Infineon put it on October 2, 2001, before the Hynix deal was announced, "Sadler said that Micron will close production the last two weeks of December, disregards of Samsungs decision."[58] Likewise, an Elpida document states: "Base on today's Goldman Sachs Technology, a reliable source from Taiwan told them that there could be an unwritten understanding among all global DRAM producers except Samsung to cut production by 20% starting November… However, Samsung isn't joining and Hynix's cash flow problem are the questions whether it can help."[59]

An exchange between Mr. Corwin (Infineon) and Mr. Mackowiak (Samsung) on November 20, 2001, signaled the change in Samsung's behavior.[60] Mr. Corwin – "You couldn't finish off Hynix and now you guys don't have the courage to increase contract pricing. All in all I'm not too impressed. So if you don't mind we will." Mr.

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[55] *Deposition of Steve Appleton*, p. 49.
[56] MU00598102-4.
[57] "Chip Price Rise Blamed on Koreans," *Financial Times*, November 26, 2001.
[58] ITNA01148349.
[59] EMUS61723.
[60] SSI0010125469.

Mackowiak – "let's talk by phone. Tell me where and when and I will look in to it." Also on November 20, 2001, an Elpida employee reported from a conversation with Samsung that Samsung intends to raise prices for Dell.[61]

By December 2001, communications among the companies indicate that price coordination among competitors has been re-established. On December 7, 2001, an Elpida employee, responding to a price forecast, states that changes in prices "are pretty much unrelated to true market forces. There is no organic reason for prices to increase i.e. demand increases. This is purely supply control. Suppliers are losing hundreds of millions of dollars. As with any commodity business, the only way to fix that is correct supply demand balance."[62] On January 4, 2002, an Elpida message chain that begins with reports of prices to Dell for Infineon, Micron, Samsung, Toshiba and "N," contains the response: "Give Lin a raise… he has singlehandedly raised the DRAM price throughout the U.S. and the world" and concludes with the response: "Give a little credit to the boys in Seoul, too."[63] A January 24, 2002, Micron document states: "Information sharing with Elpida… We both concur that the current shortage is primarily due to capacity utilization in the industry. Although there is some increase in demand, it is modest compared to the capacity throttling. The factors that led to the recent shortage are most likely due to Hynix shutting down OR to retool, Elpida capacity reduction, and Micron capacity reduction. These events combined at the end of the year."[64]

**The Nature and Extent of Collusion**

The preceding section provides evidence about coordination of pricing and

[61] EMUS063597.
[62] EMUS232713.
[63] EMUS068099.
[64] MU00057337.

production among the defendants. It focuses on the beginning period (1997 through 1999), the 2001 price war, and the re-establishment of coordination in late 2001. I have reviewed documents for the entire period from late 1997 through spring 2002, and have found extensive evidence of this kind of activity throughout the entire period. In particular, contacts among the competitors involved two competitively sensitive issues. The first was pricing. Whereas much of the contact is about specific prices to specific companies during periodic contract renegotiations, there also was discussion about prices in general, including spot prices. Second, on occasion the contact between competitors focused on the issue of worldwide supply. During the second half of 2001, this contact was extensive, coming to a close in December when several companies withdrew supply.

Whereas in each time period not all defendants or predecessor companies are mentioned in documents that report information sharing and cooperation, at some point each of the defendants was involved, as well as several other companies that are not mentioned in the *Complaint*. Because the preceding section focuses on Elpida, Hynix, Infineon, Micron, NEC and Samsung, here I will cite the documents reveal the participation of the other defendants – Mosel-Vitelic, Nanya and Winbond – in the exchange of information about prices and output.

*Mosel-Vitelic*

As noted above, Micron's *Statement of Conduct* reports that Mike Sadler of Micron discussed the problem of excess supply in the industry with Mosel-Vitelic Vice President John Seto. The following are examples of Mosel-Vitelic documents report information exchange with competitors.

- August 23, 1999: Exchange price and quantity information with Winbond.[65]
- August 23, 2000: Reports discussion with Micron about keeping prices firm.[66]
- October 17, 2001: States intention to discuss prices with Micron.[67]
- October 31, 2001: Discussions with Vanguard and Winbond about prices for Hewlett-Packard and Asustek.[68]
- November 20, 2001: States: "Micron, SS and Hynix all are trying to control the selling till 128M reaches @2.00 and DDR hits $3.00+ which can happen and is expected to occur shortly. Remember that I think it is supplier drive up-tick and not broker driven!"[69]
- February 1, 2002: Reports from Hynix, Micron and Samsung about spot market availability and prices.[70]

In addition, Mosel-Vitelic Vice President Thomas Chang was quoted in an article about joint supply reductions among Taiwanese DRAM manufactures as follows. "Our preliminary agreement is to trim some production by September."[71]

*Nanya*

Contacts between other companies and Nanya executives are mentioned in the discovery material from other companies, as cited above. Micron's *Statement of Conduct* refers to contacts between Mike Sadler of Micron with two Nanya executives. One was Kenneth Hurley, and the discussions were about pricing to Dell, but Micron states that

[65] MVC025829-30.
[66] MVC031314.
[67] MVC053886.
[68] MVC045871.
[69] MVC054191.
[70] MVC048665.
[71] WECA36170.

the attempt to prevent Nanya from setting lower prices did not succeed. Mr. Hurley testified that occasionally he would call Mr. Sadler to determine whether competitors were telling the truth about Micron's prices.[72] The other was Charles Kau concerning problems of excess supply in the industry and the unwillingness of Samsung to reduce production in the fall of 2001. Micron also reports that Steve Thorson of Micron had discussions with Kenneth Hurley about prices for Compaq and Dell, and about Nanya's plans regarding Gateway.

Charles Kau also was mentioned as willing to participate in joint production cutbacks in the same article that quoted a Mosel-Vitelic article about mutual reductions in supply by Taiwanese DRAM manufacturers. Kau was quoted as follows. "Everyone is feeling the need of cutting production. As of how to engage in the cut is an issue that needs to be discussed."[73]

Discovery directly from Nanya has not produced documents that reflect the Nanya side of the communications that are reported by the other defendants. The following is the only Nanya document that I have found that refers to contact with competitors about pricing.

- March 1, 2001: States: "I'll check with our competitors to see were we are in relation to their quotes."[74]

*Winbond*

Winbond appears in Micron's *Statement of Conduct* in reference to contact between Danny Lin of Micron and Franz Lau of Electa, a Winbond distributor. Mr. Lin and Mr. Lau discussed pricing by the two companies to Seagate. Winbond also is

[72] *Deposition of Kenneth Hurley,* p. 16.
[73] WECA36170-1.
[74] NTC073012580.

mentioned in some documents discovered from its competitors, as cited above. In addition, the following Winbond documents discuss information from competitors.

- August 9, 2001: In discussion of price and availability of product, states: "Regarding worldwide DRAM inventory: It is easily foreseeable that there is no shortage on supply. It is only artificially hold back to drive prices up, which didn't really work out yet."[75]
- November 20, 2001: In discussing price trends, states: "There seems to be some consensus among vendors to curb the shipment in order to maintain the price level. I don't think it would last long unless there is a production cut from the top vendors."[76]
- January 17, 2002: Reports prices offered by "Korean and U.S. vendors."[77]
- January 29, 2002: reports confirmation of price by Samsung.[78]

*Summary*

The documents cited in this and the preceding section contain reports of contacts among all of the defendants in which price and production information was shared. Thus, I conclude that the evidence does not support the view that any of the defendants could be categorized as innocent bystanders who happened to benefit from collusion involving others. While collusive behavior in this industry could not be expected to have had an effect on prices without the participation of the largest suppliers, and whereas most of the contact was among the biggest players, the smaller players also were involved, including several that are not mentioned in the *Complaint.*

[75] WECA 35667.
[76] WEC002869.
[77] WEC003517.
[78] WECWECA19185.

**Anticompetitive Harm**

The preceding sections document that the defendants engaged in extensive sharing of competitively sensitive information about prices and production. But the exchange of information, even when legally prohibited, does not necessarily imply that the competitive process was harmed. I now turn to this issue. This section explains how information exchange can lead to higher prices, and the conditions that make such an effect more likely.

The starting place for understanding how collusion can work is the process by which prices are established in competitive markets. In a competitive market, competition among sellers causes prices usually to be set at the average cost of production, where average cost includes a return on investment that is sufficient to enable the firm to attract investors. Because firms seek to maximize profits, all firms would like to be able to set price above the average cost of production. In a market that contains many sellers, however, firms can not achieve this objective for long.

A competitive market contains many firms (say, N), each of which has a small fraction of total sales, 1/N. Suppose that one firm observes that all of the other firms are charging a price, P, that exceeds average cost, C, by an amount d ($P = C+d$). The first firm can set the same price, obtain a market share of 1/N, and earn excess profits of $d(1/N)Q$, where Q is total industry sales. Alternatively, the firm can capture all sales by charging less than the price set by the others. For example, assume that the highest price at which all customers will switch to the price-cutting firm is $C+e$, where $0 < e < d$. At the latter price the firm might expect to earn profits equal to eQ. If the difference d-e is small compared to the difference $Q - (1/N)Q$, the price-cutting strategy is more attractive.

But all other firms will have the same incentive to cut price. If price-cutting ensues, the process will continue until P = C, at which point a further price cut is unattractive because it produces negative profits even if it succeeds in capturing all sales.

The logic of this argument hinges on the incentive for each firm to cut price, which in turn depends on either the assumption that other firms will maintain a higher price or that the high price is temporary and soon will be cut by other firms seeking to earn more profits by capturing more market share. A reasonable further assumption is that if one firm cuts price, other firms will notice their lost sales and will respond by cutting price themselves. Thus, a forward-looking firm would expect the price soon to fall to P = C. In this case, the motive for a price cut is to experience a short period of greater sales at C+e before all possibility for excess profits is lost when P = C.

The preceding sketch of competitive price theory provides insight into how collusion might work to sustain P = C+d. The key is that firms must believe that competitors will not follow their short-term incentive to engage in competitive price-cutting to obtain a temporary advantage in sales and profits. If one firm believes that all other firms are committed to set P = C+d indefinitely until someone else breaks the pledge to keep price high, then the alternatives available to that firm are as follows. First, it can earn d(1/N)Q indefinitely. Second, it can earn eQ briefly, and no excess profits thereafter when competition breaks out and forces P = C. If "indefinitely" is long enough in comparison to "briefly," then the first option is more profitable. Hence, the key to successful collusion is causing firms to believe that competitive price setting will be sufficiently rare and infrequent that collaboration (and resisting the temptation to gain short-term competitive advantage) is the more profitable pricing strategy.

Information exchange facilitates collusive pricing if it increases the likelihood that each firm will believe that its competitors are adhering to the agreement to set price above average cost. Communication about pricing intentions is a means to assure competitors that price cuts are not in the offing. Communications about production plans are a means of communicating to competitors that a firm has limited ability to profit from a price cut by increasing market share. For this reason, economic analysis leads to the conclusion that information sharing among horizontal competitors about future prices and production is undesirable because its only possible effect is to reduce the intensity of competition and thereby to harm consumers.

Whereas communications *can* facilitate collusive pricing, it will not necessarily have any effect. One problem is that firms simply may not tell the truth, so that any firm that relies on these communications finds itself with a high price but no customers. Thus, participants in a collusive arrangement must have some other means of authenticating that others are behaving as they promised. If not, any firm that suffers a temporary decline in sales for any reason may blame its competitors for cheating on the agreement and start cutting price, even if the fall in sales is for other reasons. Another problem is that the number of firms exchanging information may account for a small fraction of industry output, so that actions by firms that are not sharing information or otherwise participating in collusive pricing undo the effects of collusion among those who are coordinating price and output decisions.

Following the preceding logic, economists have identified conditions under which exchange of price and output plans is likely to cause prices to exceed the competitive level. These conditions are: (1) the market is sufficiently concentrated that a large

number of firms do not need to engage in price collusion and information exchange; (2) the group of firms that is engaging in collusion has a sufficiently large share of the market and barriers to entry are sufficiently high that the colluding firms acting together can affect price; (3) all colluding firms produce similar products so, first, there is something to be gained from collusion (which would not be the case if the products were not substitutes), and second, buyers have little reason to choose among sellers other than on the basis of price; and (4) the number of buyers and separate transactions is large, so that any firm quickly can tell if it is not capturing a reasonable share of sales, presumably because one or more of its competitors are cheating on the collusive arrangement.

A fifth factor that can facilitate collusion is the presence of institutions that discourage aggressive competition. For example, economic regulation sometimes sets price floors and limits entry, as did airline regulation before the industry was deregulated in the late 1970s. Another example is the original form of environmental regulation, which set higher emissions standards for new firms and for capacity expansion by old firms than were set for established production facilities. By imposing costs on capacity expansion, the old system of source-specific standards regulation limited the ability of firms to gain market share by cutting price, and so encouraged collusive pricing.

I believe that all of the factors that encourage collusion are present in the DRAM industry. The reasons are as follows.

*Concentration*

In my *Expert Report* I cited the market shares of the leading firms in DRAM for the period 2000-2002. In light of my conclusion that the information exchange among DRAM suppliers began earlier, I have extended these data to include 1998 and 1999,

which are reported in Table 1. The table continues to mix sources because of my inability to find complete information for all years from the same source. Each of the organizations that estimates market shares uses a slightly different method and reports slightly different numbers; however, for the firms and years for which I have several sources, I find that the conclusions about the extent of concentration are not substantially affected by the choice of data source.

The significance of the market share data is as follows. The industry has not been sufficiently concentrated to cause competitive concerns. In 1998, the Herfindahl-Hirschman Index,[79] the most commonly used indicator of the extent of competition in an industry, was below 1000. The *Merger Guidelines* of the U.S. Department of Justice and the Federal Trade Commission generally regard a market with an HHI of less than 1000 as structurally competitive, regardless of other conditions in the market.

Market concentration in DRAM increased after 1998, but by 2002 still stood below 1800. The *Merger Guidelines* state that markets with an HHI between 1000 and 1800 may or may not be structurally competitive, depending on other factors. As a practical matter nearly all merger proposals are approved if they leave the HHI below 2000. Thus, in the absence of other factors, even in 2002 the degree of concentration in DRAM supply is unlikely to cause a competitive concern.

The market share data also show that DRAM supply has never contained a dominant firm. Samsung is the leader and its share has grown; however, by 2002 its share was not sufficiently high that it would be regarded as a dominant supplier that possessed substantial unilateral market power.

[79] The HHI is calculated by summing the squares of the percentage shares of the firms in a market. Thus, a market with five firms with equal market shares of 20% has an HHI = 5(20)(20) = 2000.

Nevertheless, the combined market share of a few firms is sufficiently high that collectively they would be expected to have considerable market power. Throughout the period covered in the table the industry has had a few firms that accounted for nearly all sales. In 1998, the seven largest firms accounted for nearly 75% of industry sales. In all years from 1999 to 2002, the five largest firms accounted for more than 75% of all sales. In the presence of entry barriers, the combined market share of the leading firms is far above the threshold at which one would expect to find unilateral market power.

DRAM manufacturing has substantial barriers to entry. A barrier to entry is an impediment to the rapid construction or expansion of capacity in response to an increase in price that would cause new investment to be profitable. One example of a barrier to entry is a long lead time to enter effective production. Another example is economies of scale in production facilities, which requires that a firm obtain substantial sales to have low enough costs to be profitable. Both factors are present in DRAM production.

Semiconductor fabrication plants have economies of scale arising from "learning by doing" – that is, as a firm gains experience in producing a semiconductor product, its average cost falls substantially as the manufacturer learns new ways to reduce waste and to increase the yield of non-defective chips.[80] In addition, semiconductor products undergo rapid technological progress, forcing firms to invest in research and development to remain competitive. Learning by doing does not arise automatically from producing

[80] Douglas Irwin and Peter Klenow, "Learning-by-Doing Spillovers in the Semiconductor Industry," *Journal of Political Economy 102* (1994), pp. 1200-27, estimate that DRAM costs fall 20% with each doubling of production. Other studies reach similar conclusions, among them Andrew R. Dick, "Learning by Doing and Dumping in the Semiconductor Industry," *Journal of Law and Economics* 34 (April 1991), pp. 133-59; Kenneth Flamm, "Forward Pricing Versus Fair Value: An Analytical Assessment of 'Dumping' in DRAMs," in *Trade and Protectionism*, Takatoshi Ito and Anne C. Krueger (eds.), University of Chicago Press, 1993; Harold Gruber, "The Learning Curve in the Production of Semiconductor Memory Chips," *Applied Economics* 24 (August 1992), pp. 885-94; and Douglas A. Webbink, *The Semiconductor Industry: A Survey of Structure, Conduct and Performance*, Federal Trade Commission, January 1977.

more output, but by investing in R&D to use the manufacturing experience to improve the production process.[81] These factors create sufficiently high entry barriers that a group of firms with a market share of 75% is expected to have considerable market power.

The preceding conclusion superficially may seem to conflict with the fact that Korean and Taiwanese firms successfully entered the industry in the late 1980s and early 1990s. In fact, this entry is consistent with the presence of entry barriers for two reasons.

First, barriers to entry are a source of cost that an entrant faces. These costs do not make entry impossible if other factors offset them. In the case of Korea and Taiwan, lower wages and subsidized capital apparently were sufficient to offset the entry barriers.

Second, the barrier created by learning by doing and R&D typically applies only to a particular generation of DRAM technology. Typically, learning-by-doing benefits and R&D advances have small carry-over from one generation of DRAM technology to another – say, from 16Mb chips to 64Mb chips. Professors Irwin and Klenow find that only in the cases of the transitions from 4Mb to 16Mb and from 256Mb to 1000Mb chips did learning-by-doing cost reductions have some carryover.[82]

The period of dominance by the current cutting edge chip is typically about two years, while the underlying technology of chips changes about every five years.[83] As a result, firms that are producing the current generation of DRAM products, because of their advantages arising from having already captured learning-by-doing benefits, do not face competitive entry until the next generation of chips enters production. Moreover, even at the transition from one generation to the next, successful entry entails substantial

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[81] Nile W. Hatch and David C. Mowery, "Process Innovation and Learning by Doing in Semiconductor Manufacturing," *Management Science* 44(11) (November 1998), pp. 1461-77.
[82] Irwin and Klenow (1994), *op. cit.*
[83] *Deposition of Steve Appleton*, pp. 39-41.

risky commitments to a large fabrication plant (to enable rapid movement down the learning curve) and process R&D (to capture the learning benefits), which also are barriers to entry. In order to make the transition to a new cutting edge chip, established firms need to re-engineer an existing fabrication plant and assign new process R&D tasks to an established team of engineers. In comparison, an entrant must build a new plant and assemble a team of engineers. Consequently, the forward-going incremental cost of producing the next generation of products is lower for the incumbent than for the entrant unless the latter enjoys some other offsetting cost advantage.

Industry market shares also shed light on the expected difficulty of successful collusion in different period. The market shares of the largest DRAM firms indicate that effective collusion would be somewhat easier after the acquisition of TI by Micron in 1998, the merger of late 1999 that created Elpida, and, to a lesser extent, the acquisition of LG by Hyundai, also in late 1999. The reason is that these combinations reduced the number of firms required to form an effective collusive arrangements.

The market share data show that the DRAM industry satisfies conditions (1) and (2) above that facilitate the formation of an effective collusive arrangement. The industry is not so concentrated that one would anticipate supra-competitive prices in the absence of collusion, but it is sufficiently concentrated that a small number of firms can obtain substantial market power by coordinating their behavior. Moreover, as time has passed and the industry has become more concentrated, the number of firms that would be required to form an effective collusive agreement has declined.

*Product Homogeneity*

Products that are made by different manufacturers are homogeneous if they are so

close to being identical that buyers regard them as perfect or near-perfect substitutes. Because many agricultural products conform to this definition (a textbook example is something like No. 5 red wheat), homogeneous products typically are called commodities. The importance of product homogeneity is that it makes attaining and exercising market power more difficult. By contrast, product heterogeneity (textbook examples are designer clothing and the secret formula for Coca Cola), by differentiating one product from its nearest substitutes, sometimes can enable a firm to possess market power over the subset of buyers that places substantial value on the differences among products that otherwise are similar in description and function.

My *Expert Report* and *Reply Report* describe at length the nature of DRAM products and explain why, for any given DRAM technology, the products of different firms are homogeneous and therefore close substitutes. I will not repeat this analysis here, but instead incorporate it in this report.

Further examination of the evidence as well as economics research supports the conclusion that DRAM is widely regarded as a commodity. All of the economics research on the semiconductor industry in general and on DRAM in particular regards DRAM as a commodity.[84] Likewise, industry executives have testified that DRAM is a commodity.[85] Thus, I conclude that within a technology category DRAM is a homogeneous product.

*Structure of Demand Side of DRAM Market*

Condition (4) above that favors effective collusion relates to the extent of competition on the demand side of the market. To continue to set a collusive price, firms

[84] See, for example, Irwin and Klenow, *op. cit.*, p. 1212, and Hatch and Mowery, *op. cit.*, p. 1462.
[85] See *Deposition of Daniel Donabedian* (Elpida), p. 29, *Deposition of Farhad Tabrizi* (Hynix), pp. 120, 130-9, and *Deposition of Steve Appleton* (Micron), pp. 33-43.

must believe that it is reasonably likely that other firms also will set the collusive price. Firms may be uncertain whether their competitors are being faithful to the collusive arrangement. This uncertainty is reduced by making inferences from their own rate of sales; specifically, a fall in sales is a signal that collusion is breaking down.[86]

Collusion is more likely to be effective if the number of transactions is great and if buyers lack market power – that is, concentration of purchases among buyers is low and buyers do not engage in effective collusion. Frequent transactions enable each firm to receive substantial, continuous information about its own success in the market as well as lead to more reliable public information about price trends. For example, in an industry that produces a homogeneous product and that contains ten firms with equal costs, each firm expects to account for roughly ten percent of total sales. In such an industry, as long as each firm sets the same price, buyers have no basis for selecting any particular supplier, and so can be expected to pick sellers randomly, which makes it difficult for a firm to know whether a drop in sales is due to bad luck or a failure to meet competitive prices.

Consider two industries that have the same annual sales revenue and the same number of firms (ten). Suppose that one industry sells 10,000 units of product per week at a very low price in a large number of separate transactions to different customers, while the other sells one unit per month at a very high price. In the 10,000-unit industry, a firm, which expects to sell 1,000 units per week, can easily and quickly observe if a competitor is charging a lower price, for then its sales will fall far below its expected 1,000 units. If cheating does occur, a firm can detect it and adjust its price with a small

[86] The analysis to follow is a simplified version of the classic model of collusion by Edward J. Green and Robert H. Porter, "Noncooperative Collusion under Imperfect Price Information," *Econometrica* 52(1) (January 1984), pp. 87-100.

loss of sales and profits. But in the industry that sells one unit per month, a firm facing random buyers expects only one sale per year, and is nearly as likely to make zero sales in a year as to make one! Hence, the process of learning that others are cheating on a collusive arrangement is likely to cost the firm a year or more of sales and profits.

By the same token, a firm in the industry that sells 10,000 units per week has a much weaker incentive to cheat on a collusive arrangement, for it can expect to capture only a temporary and minor increase in annual sales and profits. But in the industry that sells a unit per month, a cheater can expect to capture the entire annual sales of several competitors before its cheating is detected. Of course, detection is facilitated in both cases if firms exchange price information about their quotes to each buyer. These exchanges give sellers a basis for anticipating the purchase decisions of a buyer, and so provide a quick method of authenticating the price information that competitors provide.

Collusion also is less likely to be effective if buyers have market power. A buyer that accounts for a large fraction of sales and that detects that price is substantially above average cost may be able to undermine collusion by offering one or a few sellers a very large sale (a large increase in market share) at a substantially lower price, enabling a cheating firm to earn greater profits from a lower margin on much more output.

I have examined the transaction data from the defendants as well as other evidence to analyze whether the demand side of the market favors or disfavors collusive behavior among DRAM sellers. For the transaction data, the economists at Brattle Group have calculated the share of sales of the five largest buyers for each quarter from the beginning of 1999 through the end of 2004. Focusing on 1999-2002, the largest buyer almost always was Dell (once Kingston was first and Dell second), and Dell's share of

sales ranged from 11.7% to 19.7%, with the latter being the largest share of any buyer in any quarter during this period. Market shares in the range enjoyed by Dell are not regarded by economists as sufficient to give any firm unilateral market power.

Among the other firms, shares of purchases rarely exceeded ten percent. For the fourteen quarters in the period, Kingston exceeded ten percent four times, Hewlett-Packard exceeded ten percent twice, and IBM and Sun each exceeded ten percent once. The combined market shares of the top five firms ranged from 34.0% (in 2000I) to 53.2% (in 2002I), with the shares being between 40% and 45% in eight of the 14 quarters. The average combined share for the top five buyers over the entire time period was 43.4%. Concentration was lower among buyers than sellers, and buyer concentration was far below the level that is necessary to raise doubts about whether the demand side of the market was structurally competitive.

The DRAM market has two other demand-side features that are favorable to effective collusion: a high number of transactions, and fragmentation of purchases by each single buyer. Although large buyers typically sign long-term contracts, among the largest buyers these contracts have neither a fixed purchase commitment nor a pre-determined price. As I explained in my *Expert Report*, contracts typically contain a provision whereby prices are renegotiated periodically, and a commitment by the buyer to a minimum fraction of its total purchases. Among the contracts that I reviewed, half specify a renegotiation period, but the renegotiation period varies from daily to annually. Some contracts call for ongoing renegotiation – that is, when either party wants to renegotiate. Still other contracts have a "most favored customer" (MFC) clause, whereby the price is either that charged to the most favored customer (or similar type of customer)

or the lower of the MFC price and a specified contract price that in turn is subject to periodic renegotiation. One contract (between Micron and Compaq) sets price equal to the lower of the pre-specified contract price and the spot price plus 3%. A few contracts call for renegotiation whenever market prices change – some calling for renegotiation regardless of the direction of change, and others only when market prices fall.

The contracts typically do not specify a quantity to be purchased. Instead, the contracts typically require the buyer to forecast purchases between three and twelve months in advance, with a commitment by the seller to provide that much. In some cases, the buyer commits to buy a minimum fraction of its total purchases from the seller. This fraction varies from 15% to over half, with larger buyers making smaller percentage commitments. Buyers prefer to acquire DRAM from more than one producer as a means to protect against unanticipated production shortfalls by a supplier. But the practice of dividing purchases among two or more sellers also reduces the incentive of a seller to cheat on the collusive agreement. A seller that cuts price may increase its share of sales to that customer, but only by a fraction of that customer's sales, not the entire amount purchased. A seller that undercuts the collusive price also may lose the benefit of the collusive agreement on subsequent sales to other buyers as its cheating causes others to be reluctant to trust its price commitments.

For the most part, because both price and quantity are variable in nearly all contracts, buyers and sellers are constantly renegotiating terms. Even when a large buyer has contracts with several sellers, the price associated with each is likely to be adjusted once or twice a month, if not more frequently, with the possibility of a change in a seller's share of sales to a customer if the relative prices among sellers change. As a

result, each seller quickly can detect any rise or fall in the attractiveness of its offerings in comparison to those of its rivals. These renegotiations give a firm numerous observations on whether its rivals are behaving according to the information that they have supplied to competitors, thereby making the collusive arrangement easier to enforce.

For the reasons given above, I conclude that the structure of the demand side of the DRAM market is favorable to effective collusion. Sellers do not face buyers with market power, and have many ongoing opportunities to collect information that enables them to draw inferences about whether competitors are behaving in a manner that is consistent with their promises.

*Institutional Environment*

The last factor that is relevant to ascertaining whether a market is susceptible to effective collusion is the broader institutional environment. In this case, an important element of the institutional environment is antidumping policy, which is widely regarded as a powerful force to encourage collusive behavior.

The U.S. and all other nations that account for a significant fraction of DRAM production are members of the World Trade Organization (WTO). Members of the WTO that are regarded as relatively developed are generally committed to free trade, but a major exception is that the WTO allows each nation to adopt an antidumping policy within guidelines set forth by the WTO. The gist of antidumping policy is that a nation can impose a countervailing duty (a tariff) on an imported product if the seller is found to have "dumped" the product into the domestic market.[87] Conceptually, dumping is defined as selling a product in a foreign market at a lower price than it is sold

[87] For a thorough discussion of antidumping, see Bruce Blonigan and Thomas J. Prusa, "Antidumping," in *Handbook of International Trade*, E. K. Choi and J. Harrington (eds.), Basil Blackwell, 2002.

domestically or at a price that causes the seller to suffer financial loss. The idea is to prevent firms, especially firms that are supported by governments, from maintaining employment levels by selling products internationally at a loss while remaining solvent by selling at a profit in a more protected home market.

In practice, the rules for detecting dumping are vague and lead to the conclusion that dumping has occurred in a wide variety of circumstances in which the accused firm has done nothing more than compete aggressively in a manner that is consistent with profit maximization. For example, firms have been found to have dumped because they increased market share when price was falling, or to have sold products during a downturn in the market at a price below the long-run average cost of production, including fixed and sunk costs in facilities and R&D that were undertaken in prior years.

If the domestic market is competitive and domestic producers are efficient, antidumping policy can create a circumstance in which domestic price is determined by domestic production capacity, not the world balance of demand and capacity. That is, if the domestic share of world demand exceeds the domestic share of world production capacity, then, in a market downturn, the domestic competitive price can be maintained above the world price by using antidumping rules to reduce the supply of imports. If this result occurs, domestic suppliers have built the evidentiary basis for subsequent antidumping cases because, if domestic price exceeds the world price, importers can not sell in the domestic market at the world price without violating antidumping rules.

The logic behind the conclusion that antidumping facilitates collusion is as follows. First, by separating the domestic market from the world market and increassing concentration in the former, antidumping reduces the number of firms that are required to

create a combined market share that is sufficient to confer substantial market power among colluders. Second, importers know that they can not undercut the domestic price without being accused of dumping, and so they have nothing to lose and something to gain by reaching a collusive agreement with domestic suppliers about the domestic price. Third, because every industrialized nation – including Japan, the European Union and the U.S. – has similar antidumping rules, the incentive to collude is omnipresent, creating an environment that encourages world-wide collusive agreements.

Antidumping is even more likely to promote collusion if the domestic market is not competitive. If domestic production is highly concentrated, and if imports are curtailed by a countervailing tariff, domestic firms can exercise market power by raising the price. The domestic industry can then offer external producers the choice of competing for the rest of the world market and being excluded from the domestic market, or entering into a worldwide collusive agreement that elevates prices everywhere. Such an agreement then leads antidumping regulators to become the enforcer of the collusive agreement, for if a participant in collusive pricing sneakily tries to gain market share anywhere by undercutting the collusive price, it will face an antidumping charge in the nation where it made the sale because the sale was at a price below the world price.

The analysis in the preceding paragraphs is widely accepted among trade economists. The consensus view is as follows: "The evidence about antidumping cases can lead to only one conclusion: antidumping regulations and measures create or sustain anticompetitive behavior…"[88]

[88] Patrick A. Messerlin, "Competition Policy and Antidumping Reform: An Exercise in Transition," in *The World Trading System: Challenges Ahead*, Jeffrey J. Scott (ed.), Institute for International Economics, 1996, p. 219. In their review of research on antidumping, Bronigan and Prusa, *op. cit.*, reach the same conclusion. See also Richard J. Pierce, Jr., "Antidumping Law as a Means of Facilitating Cartelization,"

DRAM production has been one of the most active areas of antidumping policy. In the 1980s, an antidumping case against Japan led to the "voluntary export restriction" (VER) agreement between Japan and the U. S.. The VER was essentially a government-sponsored collusive agreement to divide the DRAM market, and had the effect of keeping prices artificially high. Because higher prices lead to fewer sales, and fewer sales imply less cost reduction arising from learning by doing, the VER also served to elevate average cost.[89] In 1993, the U. S. ruled that Korean DRAM manufactures had dumped DRAM in the U. S. market during 1991-2, and imposed countervailing duties on Korean producers (Hyundai, LG and Samsung). The U. S. reviewed this finding beginning in 1996, and in 1997 ruled that the countervailing duties should be kept in place.[90] After the WTO remanded this decision because the U. S. had failed to follow its own procedures, the U. S. again ruled – on March 31, 1999, the day before the Antitrust Division states that collusion began – that the duty should be retained.[91]

In the decisions cited above, the government cited two reasons that the antidumping order against the Koreans should not be revoked, both of which were based on the behavior of the Koreans during the market downturn of 1996-7. The first was that

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*Antitrust Law Journal* 67 (2000), pp. 725-43; Maurizio Zanardi, "Antidumping Law as a Collusive Device," *Canadian Journal of Economics* 37(1) (February 2004), pp. 95-122; and Thomas J. Prusa and Susan Sheath, "The Economic and Strategic Motives for Antidumping Filings," *Weltwirtschaftliches Archiv* 138(3) (2002), pp. 389-413.

[89] For a detailed examination of the anticompetitive effects of these events, see Kenneth Flamm, *Managed Trade: Strategic Policy and the Semiconductor Industry*, Brookings Institution, 1996. The cost effects of the VER are estimated in Irwin and Klenow, *op. cit.*

[90] "Dynamic Random Access Memory Semiconductors of One Megabit or Above from the Republic of Korea: Preliminary Results of Antidumping Duty Administrative Review and Notice of Intent Not to Revoke Order," *Federal Register* 62 (52) (March 18, 1997), pp. 12794-99. The economic costs of this decision and the prior episode with Japan are discussed in Douglas A. Irwin, "Antidumping: The Semiconductor Industry," in *Brookings Trade Forum*, Robert Z. Lawrence (ed.), Brookings Institution, 1998, pp. 173-200.

[91] "Final Results of Redetermination in the Third Administrative Review of the Antidumping Duty Order on Dynamic Random Access Memory Semiconductors of One Megabit or Above from Korea," March 31, 1999, available at ia.ita.doc.gov/remands/dram-1m.htm.

the Koreans were expanding output during a general period of falling prices and excess supply, and the other was that in some cases the Korean's set prices below "normal value" in the U.S., which is long-run average cost (including interest, R&D and administrative overhead).[92] Consequently, the government concluded that a further market downturn would be likely to lead the Koreans to increase the proportion of sales below normal value, which would be dumping. The ruling also observed that the Koreans had announced plans to reduce production, but that these plans may not have been carried out.

The implication of these ruling is that had the Koreans responded to lower prices by reducing output, they probably would not have faced continued enforcement of the antidumping order. The antidumping order essentially eliminated the possibility that foreign firms could cut prices that were above marginal cost but at or below average cost as a strategy for maximizing profits and preserving sales. By foreclosing this option, the antidumping ruling makes collusion to reduce supply more attractive. Instead of facing the choice of reducing output unilaterally or giving up operating profits in the U. S. market (remember, if price is below "normal price" but above marginal cost, each sale has positive operating profits), the Koreans can participate in a mutual plan for all suppliers to curtail output, driving up prices and margins everywhere in relation to the competitive outcome during a market downturn. This alternative is attractive to others as well because it drives up prices everywhere, not just in the U. S.

[92] An important feature of antidumping rules is that the concept of "normal price" is not the concept of a profit-maximizing price or even of a predatory price in antitrust economics, both of which equal marginal cost or, as an estimate, average variable cost. In the short run, such as during a temporary market downturn when firms have excess capacity, marginal cost excludes capital costs and other historical sunk costs. Even in the long run, marginal cost excludes costs that do not depend on output, such as R&D and certain components of administrative overhead. Thus, the normal price in antidumping proceedings usually is higher than the profit-maximizing price during a period of weak demand, as well as above marginal cost, which is used as the benchmark in a test for predation.

My review of the antidumping policies of the U. S. regarding DRAM leads me to conclude that these policies did increase the incentive for collusion in this industry. Moreover, the decisions of March 1997 and March 1999 created the prospect that the Korean firms would never escape the U. S. antidumping order unless they reduced their share of output. This prospect increased the financial incentive to reach and then to follow an agreement among all suppliers to engage in mutual reductions in output.

*Summary*

Conditions in the DRAM industry in the late 1990s were conducive to effective collusion. The number of suppliers was too high for any to expect to have unilateral market power, but small enough to make coordination and enforcement practicable. The product is homogeneous, so that firms can not carve out a profitable, protected market through product differentiation. The demand side of the market was competitive and was characterized by a large number of low value transactions, which also was conducive to seller collusion. Finally, U. S. antidumping policy enhanced the incentive to collude by setting and enforcing an anticompetitive standard for determining whether foreign producers were dumping into the U. S. market.

The presence of these conditions does not prove that collusion took place. Instead, the point is that collusion, if attempted, was likely to succeed. This analysis fits into the preceding analysis about the exchange of information, which is another mechanism for making collusion more attractive by increasing the likelihood that firms will adhere to collusive agreements.

**Breadth of Collusion**

In the plea agreements with the Antitrust Division, guilty pleas are entered for

collusion against only six large manufacturers of PCs. This section examines the issue of whether the effect of collusion was broad, affecting all customers.

This issue also is examined at length in my two earlier reports, and I incorporate that analysis here. Further work supports my earlier conclusion.

The internal documents, depositions and Micron's *Statement of Conduct* cited in previous sections describe three types of information exchange: specific price, general price, and output.

The first form of information exchange is discussions of prices for a specific buyer or type of buyer. Most of these documents deal with the six leading PC manufacturers, but by no means do all such documents deal with these firms. Examples cited elsewhere in this report include multiple references to Sun, including coordinating behavior at the Sun reverse auction,[93] as well as occasional references to others and to the spot market. In addition, Micron's *Statement of Conduct* describes contacts between Mike Grant of Micron and David Lin of Elpida concerning DRAM for servers.

The second form of communication is general discussions about prices. In fact, some contracts base the contract price on list price. Thus, discussions about general prices or price ranges include discussions that would have had an effect on all customers, not just the major OEMs. There would be no need to discuss those customers specifically since the effect of price collusion on them would follow automatically from an agreement on general prices.

The third form of communication is discussions about future output. In particular, the discussions among Taiwanese vendors, Korean vendors, and Japanese vendors, as

[93] See, for example, ITNA01021494-6 and EMUS383442-3, reporting conversations among Elpida, Infineon, Mitsubishi and Samsung about coordinating participation in the Sun auction.

well as the tour organized by Mr. Sadler of Micron, about coordinating output reductions, if they had any effect at all, would have affected all buyers, not just the six large OEMs.

My previous report included substantial information about the causal link among major contract prices, secondary contract prices, and spot prices. I have undertaken further work along these lines, based upon the evidence about the price terms of contracts as well as discovery material. In particular, as discussed elsewhere, contracts have renegotiation periods of varying durations. Most of the large customers – the major contracts – either call for fairly frequent renegotiation or contain "most favored customer" clauses. Some trigger renegotiation on a change in market conditions, which is first observed as a change in spot prices. The documents cited in my *Reply Report* confirm that changes in spot prices are likely to be used by one side or the other to trigger revisions to contract prices.

From this material, one would expect that spot prices would have an effect on major contract prices with a relatively short delay – corresponding to renegotiation periods of one or twice per month – whereas the effect on secondary contracts, which tend to have longer renegotiation periods, would be more protracted. This conclusion is consistent with the testimony of Mr. Lauer of Micron, who was asked: "Did you see whether there was a lag period between contract relative to spot prices, either on the way down or the way up?" He replied: "Typically, there would be a lag as represented by the customer's own price negotiation profiles. Spot prices move every second. Whereas the computer OEM, the big PC account guy, can't negotiate that frequently."[94]

Using the DeDios data on average prices that are described in my previous

[94] *Deposition of Bill Lauer*, p. 106. He also testified (p. 110) that regional spot prices were not different in different regions, which confirms that the market is world wide.

reports, I have undertaken a causality test on the relationships among major contract price, secondary contract price, and spot price for the period for which we have DeDios data.[95] The basic specification is to estimate one of these three prices at a given time, using as independent variables lagged values of the same price as well as the other two types of prices. If causality between two prices goes in only one direction, then the causing price will be statistically significant in the equation predicting the caused price, but the caused price will not be statistically significant in the equation predicting the causing price. In addition, fixed effects are included in each equation for each size and technology of DRAM and for the periods of collusion and competition described above.

The main results are reported in Table 2.[96] Past spot prices cause major contract prices and secondary contract prices, with the first effect distributed over both the two-week and four-week periods and the second effect experienced only in the four-week period. These results are consistent with the fact that larger contracts tend to have more frequent price adjustments. By comparison, major contract prices do not cause spot prices. Thus, the basic causal description above fits the data well. The close causal relationship between spot prices and contract prices is confirmed by these results.

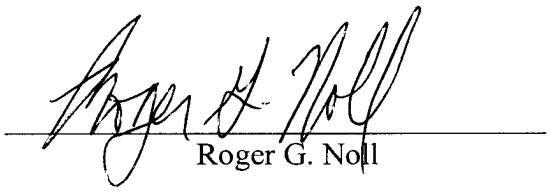
**Conclusion**

The purpose of this report is to use economic analysis to explain why the information sharing of the defendants is likely to cause anticompetitive harm to consumers. This report explains why the market for DRAM is susceptible to conclusion, and why the exchange of information among defendants is likely to cause harm to buyers of DRAM by elevating prices in the short run (be reducing the incentive to engage in

[95] Because the transaction information from the three defendants that have provided it does not indicate the form of the transaction, the causality test can not be formed on those data.
[96] Other specifications were estimated with qualitatively similar results.

price competition) and in the long run (by reducing output, and thereby, through the learning curve effect, to cause costs to be higher). The key findings of this report are: first, the defendants did engage in persistent and extensive sharing of information about prices and output plans that is more consistent with collusion than with competition; second, the conditions of the market for DRAM favor effective collusion, which is facilitated by such information sharing; and third, the collusive activities were not limited to just major contract customers.

I declare that the foregoing is true to the best of my knowledge and belief.



Roger G. Noll

Executed at Stanford, California, on August 25, 2006.

**Table 1: DRAM Market Shares, 1998-2002**

| *Firm* | **1998** | **1999** | **2000** | **2001** | **2002** |
|---|---|---|---|---|---|
| Samsung | 20.4 | 22.9 | 21.1 | 27.0 | 32.5 |
| Micron | 8.9 | 16.0 | 18.9 | 19.6 | 18.2 |
| Hynix[a] | 10.8 | 20.3 | 17.2 | 14.9 | 12.8 |
| Elpida[b] | * | * | 10.6 | 7.4 | 4.0 |
| Hitachi | 6.4 | 5.2 | | | |
| NEC | 9.0 | 8.3 | | | |
| Infineon[c] | 6.9 | 8.0 | 8.5 | 9.9 | 12.8 |
| Toshiba[d,e] | 4.7 | 4.5 | 6.2 | 2.4 | 1.9 |
| Mitsubishi[f] | 6.9 | 3.3 | 3.1 | 2.2 | 2.4 |
| Mosel Vitelic | 2.5 | 2.4 | 2.8 | 1.7 | 2.0 |
| Nanya[c,g] | 1.2 | 1.5 | 2.2 | 2.8 | 5.5 |
| Winbond[d] | na | na | 1.9 | 1.1 | 3.1 |

1998-2000 shares from Cahners InStat Group (MVC8846-79 at , 2001 shares from iSuppli estimates of individual company sales and Semico estimates of market size, and 2002 shares from iSupppli.

Notes to Table

[a] Hynix was formed after the merger of Hyundai and LG in October 1999. Hynix 1998 data are for Hynudai and 1999 data are for merged entity.

[b] Elpida was formed from the merger of the memory divisions of NEC and Hitachi in December 1999, and acquired Mitsubishi's DRAM business in October 2002.

[c] Infineon and Nanya entered a joint venture agreement in December 2002.

[d] Winbond entered into a joint venture relationship with Toshiba in 1999.

[e] Toshiba sold its U.S. manufacturing facility to Micron in 1998 and announced its plan to exit the industry in late 2001.

[f] Mitsubishi's DRAM business was acquired by Elpida in October 2002.

[g] 2000 Nanya share from Nanya web site at www.nanya.com/e-htm/D-E-HTM/e/E-07-1-1.asp?News_ID=37.

**Table 2: Causality of DRAM Prices**

| | *Independent Variable* | | | | | |
|---|---|---|---|---|---|---|
| | Major Contract | | Secondary | | Spot | |
| | Level | Change | Level | Change | Level | Change |
| *Dependent Variables** | | | | | | |
| 2-week Lag Major | 0.786 | -0.038 | | | -0.547 | -0.025 |
| (t-statistic) | (23.6) | (1.42) | | | (1.41) | (0.68) |
| 4-week Lag Major | -0.074 | 0.237 | | | -0.032 | -0.024 |
| (t-statistic) | (2.51) | (9.09) | | | (0.89) | (0.68) |
| 2-week Lag Secondary | | | 0.616 | -0.047 | | |
| (t-statistic) | | | (13.9) | (1.25) | | |
| 4-week Lag Secondary | | | -0.040 | -0.221 | | |
| (t-statistic) | | | (0.98) | (5.82) | | |
| 2-week Lag Spot | 0.097 | 0.119 | -0.027 | 0.001 | 0.92 | 0.077 |
| (t-statistic) | (3.50) | (5.21) | (0.68) | (0.04) | (27.3) | (2.46) |
| 4-week Lag Spot | 0.121 | 0.392 | 0.344 | 0.656 | 0.025 | 0.346 |
| (t-statistic) | (4.20) | (17.0) | (8.05) | (18.2) | (0.72) | (11.1) |
| Adj. $R^2$ | 0.99 | 0.44 | 0.99 | 0.40 | 0.98 | 0.15 |

* Fixed effects for specific product types and for collusion periods discussed above not reported.

# APPENDIX A

CURRICULUM VITAE
ROGER G. NOLL

## PERSONAL

Date and Place of Birth: March 13, 1940; Monterey Park, California

## EDUCATION

East High School, Salt Lake City, Utah, 1958
B.S. (Math, Honor), California Institute of Technology, 1962
A.M., Ph.D. (Economics), Harvard University, 1965, 1967

## SCHOLARSHIPS, FELLOWSHIPS AND AWARDS

National Merit Scholarship 1958-62
National Defense Education Act Fellowship 1962-66 (declined)
Harvard Prize Fellowship 1962-63
National Science Foundation Fellowship 1963-64
Guggenheim Fellow 1983-84
Rhodes Prize for Undergraduate Teaching, Stanford University, 1994

## POSITIONS HELD

Teaching Fellow, Harvard University, 1964-65
Instructor, California Institute of Technology, 1965-67
Assistant Professor, California Institute of Technology, 1967-69
Senior Staff Economist, Council of Economic Advisers, 1967-68
Associate Professor, California Institute of Technology, 1969-71
Senior Fellow and Co-director of Brookings Studies in the Regulation of Economic Activity, Brookings Institution, 1970-73
Professor, California Institute of Technology, 1973-82
Visiting Professor, Graduate School of Business, Stanford University, 1976-77
Chairman, Division of the Humanities and Social Sciences, California Institute of Technology, 1978-82
Reuben Gustavson Lecturer, University of Chicago, April 1981
Institute Professor of Social Sciences, California Institute of Technology, 1982-84
Donald Gilbert Memorial Lecturer, University of Rochester, December 1982
Fellow, Center for Advanced Study in the Behavioral Sciences, 1983-84
Professor of Economics, Stanford University, 1984-2006
Visiting Scholar, Hoover Institution, 1984-85
Professor by Courtesy, Department of Political Science, Stanford University, 1985-
Professor by Courtesy, Graduate School of Business, Stanford University, 1986-
Veblen-Clark Lecturer, Carleton College, May 1986
Director, Public Policy Program, Stanford University, 1986-2002
David Kinley Lecturer, University of Illinois, May 1987
Sunderland Fellow, Law School, University of Michigan, Fall 1988
Morris M. Doyle Centennial Professor in Public Policy, Stanford University, 1990-2002
Jean Monnet Professor, European University Institute, May 1991
Associate Dean, Humanities and Sciences, Stanford University, 1991-92
Visiting Professor, University of California, San Diego, 1993
Visiting Fellow, Brookings Institution, 1995-96
Nonresident Senior Fellow, Brookings Institution, 1996-99
Director, American Studies Program, Stanford University, 2001-02
Director, Stanford Center for International Development, 2002-06

## TEACHING EXPERIENCE

Undergraduate: Introductory Economics, Intermediate Microeconomic Theory, Statistical Methods in Economics, Economic History of Medieval Europe, Contemporary Socioeconomic Problems, Advanced Topics in Microeconomics, History of Economic Thought, Economic Policy Analysis, Politics of Government Reform, Economics of Sports, Antitrust and Regulation

Graduate: Public Policy Analysis, Antitrust and Regulation, Applied Microeconomic Theory, Experimental Methods

## RESEARCH INTERESTS

Applied Microeconomics, Antitrust and Regulation, Technology Policy, Political Economics, Legal Institutions

## MEMBERSHIPS ON COMMITTEES AND BOARDS

President's Task Force on Communications Policy (CEA Staff Representative and Alternate Member), 1967-68
Commerce Technical Advisory Board Panel on Venture Capital, 1968-69
Committee on the Multiple Uses of the Coastal Zone, National Council on Marine Resources and Engineering, 1968
Secretary, President's Interagency Task Force on Income Maintenance, 1968
Task Force on Application of Economic Analysis of Transportation Problems, National Research Council (NAS/NAE), 1970-73
Committee on Technological Forecasting on Behalf of the Environment, Office of Science and Technology, 1970-71
Board of Economic Advisers, Public Interest Economics Foundation, 1974-84
Executive Committee, Caltech Environmental Quality Laboratory, 1970-71
Faculty Board, Caltech, 1974-76
Advisory Commission on Regulatory Reform, Senate Committee on Government Operations, 1975-77
Chairman, Fourth Annual Telecommunications Policy Research Conference, 1975-76
Committee on Satellite Communications, National Academy of Sciences, 1975-76
Advisory Council, Jet Propulsion Laboratory, 1976-82
Chairman, Committee to Monitor the Desegregation Plan of the Los Angeles Unified School District, Los Angeles Superior Court, 1978-79
Advisory Council, National Aeronautics and Space Administration, 1978-81
Advisory Council, National Science Foundation, 1978-89
Board of Advisers, National Institute of Economics and Law, 1978-84
Research Advisory Board, Committee for Economic Development, 1979-82
President's Commission for a National Agenda for the Eighties, 1980
Board of Directors, Economists, Inc., 1981-
Review Panel, NSF Regulation and Public Policy Program, 1981-84
Board of Editors, Journal of Economic Literature, 1981-90
Advisory Board, Solar Energy Research Institute, 1982-91
Board of Directors, Cornell Pelcovits and Brenner, Inc., 1982-1988
Chairman, Advisory Panel on Information Technology R&D, Office of Technology Assessment, 1983-84
Supervisory Board of Editors, Information Economics and Policy, 1982-88
Coordinating Editor, Information Economics and Policy, 1988-92
Advisory Committee on Integrated Environmental Management Program, Environmental Protection Agency, 1983-85

**Membership on Committees and Boards, cont'd** 3

Commission on Behavioral and Social Sciences and Education, National Academy of Sciences, National Research Council, 1984-90
Advisory Panel, NSF Policy Research and Analysis Division, 1984
Director, Program on Regulatory Policy, Stanford Institute for Economic Policy Research, 1984-
Science Advisory Board, Panel on Clean Air, Environmental Protection Agency, 1985-86
Board of Editors, Review of Economics and Statistics, 1985-2002
Contributing Editor, Regulation, 1986-93
Energy Research Advisory Board, Department of Energy, 1986-89
President & Chairman of the Board, Telecommunications Policy Research Foundation, 1986-87
Board of Directors, International Telecommunications Society, 1988-92
Advisory Board of Editors, Journal of Risk and Uncertainty, 1988-
Acid Rain Advisory Committee, Environmental Protection Agency, 1990-91
Secretary of Energy Advisory Board, 1990-95
International Board of Editors, International Journal of the Economics of Business, 1993-
Faculty Senate, Stanford University, 1993-95, 98-02, 04-06
California Council on Science and Technology, 1995-2001
Panel on Universities, President's Committee of Advisors on Science and Technology, 1996
Committee on Intellectual Property and the Information Infrastructure, National Research Council, 1998-9
Board of Editors, Journal of Sports Economics, 1999-
Board of Associate Editors, Economics of Governance, 1999-
Board of Advisors, American Antitrust Institute, 2000-
Board on Science, Technology and Economic Policy, National Academies, 2000-2006

## SPONSORED RESEARCH

"Opinions of Policemen." International Association of Chiefs of Police, 1969
"Studies in the Regulation of Economic Activity." Brookings Institution and Ford Foundation, 1970- 3
"Government Policies and Technological Innovation." National Science Foundation National R&D Assessment Program, 1973-4
"The Social Consequences of Earthquake Prediction," National Aeronautics and Space Administration, 1974-6
"Nuclear Safety Regulation." National Science Foundation RANN Program, 1975-7
"The Public Television Station Program Cooperative." National Science Foundation RANN Program, 1975-7
"The Station Allocation Game." Federal Communications Commission, 1977
"Energy Policy Studies." Various donors, 1978-84
"Economics of Oil Leasing" and "Issues in Utility Pricing." Department of Energy, 1978-9
"The Economics of Boxing, Wrestling and Karate." California Athletic Commission, 1978
"Implementing Tradable Emissions Permits." California Air Resources Board, 1979-82
"Social Science and Regulatory Policy." National Science Foundation, 1980-2
"The Political Economy of Public Policy." National Science Foundation and Center for Economic Policy Research, Stanford University, 1983-4
"CEPR Program on Regulatory Policy." various donors, 1987-2006
"The Economics of Research Universities and Scholarly Communication." Brown Center for Education Policy, Brookings Institution, 1995-6
"Coordination of Regulatory Reform," Organization for Economic Cooperation and Development, 1996
"The Future of the Research University," Carnegie Foundation, 1996
"SCID Program in Economic Policy Reform," Various donors, 2002-06

## CONSULTANTSHIPS

President's Task Force on Suburban Problems, 1968

**Consultantships, cont'd**



President's Committee on Urban Housing, 1968
Special Assistant to the President, Ford Foundation, 1969
Space Technology Applications, Jet Propulsion Laboratory, 1969
Panel on the Abatement of Particulate Emissions, National Research Council (NAS/NAE), 1971
Sloan Commission on Cable Communications, 1971
President's Commission on Government Procurement, 1971
Senate Antitrust Subcommittee, 1972
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